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MATHEMATICAL PROGRAMMING FOR RESOURCE POLICY APPRAISAL UNDER  
MULTIPLE OBJECTIVES

By

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## ABSTRACT

Mathematical programming is one technique that can be used for resource policy appraisal. Multiple objectives are usually involved in resource policy considerations. This paper discusses issues regarding the use of mathematical programming techniques for the multiobjective resource policy arena. Theoretical models are introduced with a separation called for between producer response models and policy maker models due to a disparity of objectives. The paper draws on the literature citing cases where producer level models have been utilized to simulate the policy

outcome implications of alternative policies.

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## MATHEMATICAL PROGRAMMING FOR RESOURCE POLICY APPRAISAL UNDER MULTIPLE OBJECTIVES

When I was contacted about this paper, I was informed that several contexts were relevant. These are:

- \* Narrowing the topic from operations research to mathematical programming
- \* Modeling and support of environmental policy decision making
- \* Relevance to international development
- \* Inclusion of case studies

Consequently, this paper will overview multiple-objective mathematical programming as it has been and could be applied to environmental policy actions, largely from an international development context. I also should indicate that my Agricultural

Economics background will bias the presentation toward agriculture and that the time available for construction of this paper led me to draw most of the references and case studies from my own work.

### Why Examine Such a Topic?

Mathematical programming deals with the selection of decision variable values so as to maximize an objective (or set of objectives) subject to constraints. Why is such a technique relevant to Environmental and Natural Resource Policy and Training (EPAT) activities regarding resource policy in an international development setting? There are actually two contexts in which such an approach makes sense.

1. The selection by policy makers among a set of alternative environmentally related actions.
2. Producer reactions to environmentally-related policy actions.

First, let us examine the policy maker question. Policy makers potentially have many actions they may undertake. Consider policy toward soil erosion reduction. Policies could be implemented which:

- \* Subsidize particular kinds of soil management practices or related equipment.
- \* Promote educational programs disseminating information on the benefits of conservation tillage.
- \* Adopt a regulatory approach where certain practices are prohibited.
- \* Subsidize farmers so severely erodible lands are treated with

erosion control practices.

These alternatives constitute a variety of potential decisions (variables). Agency work force and budget plus numerous other factors would constrain choice among these variables. Thus, the mathematical programming structure is present. Multiple objectives would also be relevant in that policy makers might be concerned with such things as:

- a) government budget exposure;
- b) income of target groups;
- c) agricultural production;
- d) export levels;
- e) consumer prices;
- f) quantity of soil conserved;
- g) damages due to soil erosion; and
- h) water quality.

The second modeling question involves forecasting producer reactions to environmental policies. In the soil conservation example, farmers can employ a number of choices in responding to an erosion program. Alternative tillage and residue management practices, crop mix, multiple cropping, and rotations could be used. Changes in farming practices may entail different hired labor requirements. The family diet may also change in response.

Thus, a producer model could have tillage, cropping, rotation, hired labor and diet formulation variables. Constraints would involve land, family and hired labor, machinery, draft animals, family dietary requirements, crop rotations, and multiple cropping possibilities. Again, the mathematical programming structure is present. The multiple objective context is relevant from both the farmer and policy maker perspectives. The farmer could be interested in income, risk exposure, subsistence behavior, labor-leisure tradeoffs, and hired labor acceptance. Objectives for other family members could be relevant where culturally driven division of effort is important. Simultaneously policy makers might be interested in the way soil erosion rates, farm income, government cost, off farm sales, and employment are affected by farmer reactions.

Why use Mathematical Programming Particularly for Response Forecasts?

A fair question in the context of this paper is why use a programming-based methodology rather than an extrapolative (econometric or statistical) approach or a simulation model. This is a question without a definite answer. The salient characteristic of a mathematical program in this regard is that it constructs a synthetic representation of supply response based on an assumed objective and sets of variables and constraints.

As such then considerations in using alternative models are as follows:

1. Is it reasonable to think that the actions motivated by the environmental change can be extrapolated from historical behavior and is enough data present to specify the relationships from which to extrapolate? (If so, do so.)
2. Is there sufficient reason to believe there are enough possible solutions in interaction with the constraints that the range of possible solutions requires one to model goal seeking behavior rather than relying on process following simulation? (If not, consider simulating.)
3. Are the time, financial, personnel, data and other resources available in adequate quantity?

This paper will proceed assuming mathematical programming is the chosen method.

#### TOWARD A FORMAL STATEMENT OF MODELS

The programming models discussed above can be expressed formally.

#### Policy Model

Suppose the policy maker has the decision sets  $S$  for subsidies,  $T$  for taxes, and  $R$  for regulations while being interested in the outcome set  $Ob$ . Further, suppose that  $F_2(S, T, R)$  predicts the outcome set implications of the policy instruments and  $F_1(S, T, R)$  reflects usage of a set of policy constraining resources which limit policy actions. Formally a model of this can be written as follows:

In this model, the policy maker chooses values for  $S, T$ , and  $R$  while  $Ob$  gives the resultant objective.

In this model, the policy maker chooses values for  $S, T$ , and  $R$  while  $Ob$  gives the resultant objective levels and  $V(Ob)$  reflects the policy objective function. The first constraint contains the term  $F_1(S, T, R)$  giving the budgetary and other limited resource implications of selecting various actions, while  $b_1$  gives resource endowments. Simultaneously,  $F_2(S, T, R)$  gives the outcome set implications of alternative policies and these are accumulated into the outcome measures ( $Ob$ ).

This is a multiple objective programming problem requiring identification of a number of items.

1. The relevant policy decision variables are the members of the sets  $S, T, R$ .

2. The relevant objectives are the members of the set  $Ob$ . In general  $Ob$  contains a number of policy relevant outcomes. Such objectives may include diverse outcomes such as soil lost, pounds of pesticides used, carbon emissions, government subsidy costs, farm employment and earnings by small farmers.

3. The function  $V(Ob)$  values the outcomes. This is an explicit statement of government, policy maker and or donor agency preferences for the policy relevant outcomes. Some outcomes may be desirable and others may be undesirable. This function is anticipated to be nonlinear exhibiting decreasing marginal satisfaction from increasing amounts of the outcome. Specification of the function may involve a number of the techniques from multi-objective programming including elicitation (Barnett, Blake and McCarl 1982), revealed preference estimation (Brink and McCarl 1978, Weins 1976), pareto extreme point generation (Steuer 1978), decisionmaker interaction (Candler and Boeljhe 1977) or assumption/sensitivity analysis (Brandao, McCarl and Schuh 1984). Romero further discusses these issues. However, we should note that none of these approaches have been meaningfully applied to specifying  $V(Ob)$  for the policy maker problem.

4. The implications of the policy instruments for the objective outcomes is expressed in the functions  $F2(S,T,R)$ .

5. The constraints which limit policy give the dimension of the first constraint set and the endowments of the resources involved are in  $b1$ .

6. The usage of the policy constraint resources by the policy instruments are in the functions  $F1(S,T,R)$ .

Meeting requirements 3, 5 and 6 pose difficult data development tasks, while meeting requirement 4 in general is nearly impossible.

This particular model, if it could be specified (and it really never has been) would help policy makers choose the exact policies to utilize so that they maximize some particular objective. This is a normative or prescriptive policy model.

## Producer Response Modeling

Suppose producers have a set of production choices  $X$ , care about a general set of outcomes ( $W$ ) and income ( $I$ ), operate in a setting where government can subsidize, tax, and/or regulate them. Suppose  $S$ ,  $T$  and  $R$  define government actions in these three areas. A formal statement of the producer response problem is as follows:

Here resource constraints limit production response-- $H(X)$  is less than or equal to  $N(R)$ , but the resource endowment is influenced by regulations-- $N(R)$ . Farm income ( $I$ ) involves farm activity as well as subsidies and taxes-- $K(X,S,T)$ . Realization of the other farm objectives ( $W$ ) is a function of farm activity -- $M(X)$ .  $G(W,I)$  reflects the producers valuation of multiple objectives



and is setup using the same procedures discussed when defining the  $V(Ob)$  function above.

Accounting for policy-maker objectives is also included in the term  $Q(X)$ . Thus, the model depicts producer choices which are influenced by taxes, subsidies and regulations. This model is a predictive model usually used in scenario analyses to examine the producer reactions to changes in policy. This model therefore generates some of the information that would be used in the first model, and the two models conceptually can be unified as discussed below.

### A Unified Policy Maker, Policy Reactions Model

Examine the two models above. The first one chooses policy but needs predictions of the policy objective implications of producer reactions. The second starts with knowledge of the policies and generates predictions of producer reactions. This distinction is important as when policy makers impose a particular policy, they may not have a precise idea of producer reactions. Furthermore, policy makers do not control producers reactions directly, rather they only guide them through the subsidy, taxation and regulatory framework. A unified model of policy and policy reaction is as follows:

In this unified model, policy is chosen so that it maximizes the satisfaction of the policy maker but is subject to the optimal response of the producer. This model is called a multi-level model (Candler, Fortuny and McCarl 1981), but is difficult to solve. However, it is an appropriate conceptualization of the environmental policy process.

This problem has been found to be combinatorial in nature and in possession of many local optimal (Candler, Fortuny and McCarl 1981, Bard 1985). In addition results have shown that a mix of good policies may result in a bad policy, so the problem needs to be approached with care. Results have also shown that radical changes in policy may be better than fine tuning an existing policy (Candler 1981). This model is the subject of research on a number of fronts and also is related to developments in optimal control and other modeling contexts.

### Caution: Don't Use Policy Objectives with Behavioral Response Models

A common thought when looking at the above framework is why worry about the producer objectives in framing the response? Rather why not impose the policy makers objectives and constraints along with the produce response variables and constraints, then maximize satisfaction from the policy outcomes. In other words:

Why worry about maximization of the producer objective function?

Such a model follows:

This approach is wrong! Its fallacy can be argued as follows. In a programming model, the decision variable solution maximizes the objective function. Consider the following example: suppose US policy makers were simultaneously interested in maximizing

producer income, minimizing soil erosion, and minimizing imported oil. Do you think that farmers would readily sacrifice income earning potential to satisfy government desires? I doubt it.

Government only guides the decisions made by individuals, it does not specify them. Clear counter examples exist in the literature. The economic theory of externalities indicates individuals commonly generate unattractive social outcomes (i.e. polluted water) because of divergences between social and private values. In addition, water conservation motivated incentive programs have found conservation scheme adopters commonly irrigate additional acres and increase total water use defeating the conservation objective. Thus, it is important to maintain the distinction between government objectives and producer responses. Use of producer response models hopefully helps forecast unanticipated outcomes.

#### PROPER SPECIFICATION OF PRODUCER RESPONSE MODELS

Given the difficulty in solving the model articulated above, the state of the art in environmental modeling has generally involved specification of response models which:

- \* predict producer response in the face of environmental incentives.
- \* account for policy objectives; and
- \* can be used to do policy scenario analysis.

Significant differences arise in producer response models formulated at the producer, regional and or nation-sector wide levels. Here I discuss all three but feel the last is the most relevant, so spend more time on it.

#### Modeling the Response of Individual Price-Taking Producers

When the focus is on individual (or a small group) response, models are usually formulated assuming the producer is a price taker, not large enough to influence prices of traded products or factors. The main job in specifying such a model is the adequate depiction of the production response possibilities, constraints and objective function(s).

The first job is to identify variables, the largest set of which is usually the production possibilities. Here one often specifies multiple variables for production of each enterprise. For example, variables might depict the crop planted at different times with different irrigation systems and cultivation techniques. In an Indonesian study (McCarl and Van Holst Pellekaan 1982) rice variables were introduced for crops planted during different seasons using different varieties, fertilization techniques, cultivation practices and rotations. Other variables are commonly specified for factor acquisition possibilities such as hired labor, renting land and purchasing

inputs. Variables may also involve diet formation and factor sale such as renting land to others or hiring family labor to others.

The constraints must be defined so that they adequately depict the limitations on the response choice. Often there are multiple constraints for a class of factors. Models commonly are constrained by monthly or finer disaggregations of labor, irrigation water, machinery and draft power. Constraints may also specify calorie and protein requirements for a family subsistence diet (Calkins 1981) as well as a reflection of tastes and preferences.

The other important factor in the producer response model is the proper specification of objectives. The interaction of the constraints and variables usually allows thousands of possible solutions while the objective function picks the relevant solutions or solution set. In the Indonesia study, the objectives specified were profit maximization, risk avoidance and subsistence diet adequacy.

In general, production response models carry with them a number of assumptions. One is that they are a "typical" firms in a region. Such models are not usually statistically representative but are rather felt to depict production across a loosely-defined class of individuals. The models are usually set up relying on cross-section data commonly integrating producer and experimental data so as to fully portray production possibilities. Factors such as land, family labor, hired labor, water and land rental are assumed to either be available in fixed quantity or fixed price up to a maximum quantity.

Environmentally such models vary widely but the common approach is to include equations which impose regulatory limits or add up environmental items of interest. Policy relevant items can also be accounted for, commonly firm profits, labor employment, and production shipped off the farm among others are computed for policy-maker consideration.

#### Farm Level Case Example 1 -- Indonesian Technology Prospects

This study involves supply response within Indonesian agriculture (McCarl and Van Holst Pellekaan). In this study, three farm models were set up. One was a "typical farm" model for a dryland region in Southern Sumatra. The other two depicted irrigated production in Java under rainy season and year round irrigation water supply. The models depicted farm reactions to the availability of several new technologies.

Technically, the variables included crop timing, multiple crop sequences, fertilization rates, tillage power source, family diet formation, labor hiring and labor sale. The constraints included

monthly labor, land by period, tillage power availability, subsistence, fertilizer response and technology availability. The farm level objectives included income, risk and subsistence. The policy outcomes of interest included the distribution across farms of income, technology reliance, crop mix, employment, off-farm marketable surplus, land use intensity, and irrigation water usage. Production data for the study were drawn from statistical

farm budgets, as well as a set of fertilization and multiple cropping experiments conducted in farmers fields.

The models were used to examine alternative scenarios regarding sensitivity of farm technology adoption and performance measures to labor market conditions, product prices, risk attitudes, family size, farm size, draft power source and farm type. The model solutions were used as input to studies examining:

- \* the prospects for food production,
- \* the types of incentives one needed to simulate non-rice crop production;
- \* the implications of new technology for the value of year-round water control projects; and
- \* the design of a sector-wide loan program.

#### Farm Level Case 2 -- Corn Byproducts for Biofuels

The second case involves U.S. midwest farms and corn-biomass harvesting (Apland, Baker and McCarl 1981/82). In this study, farm reactions to incentives designed to stimulate the harvest of corn stover for biofuels production were examined. A farm model was set up for a "typical" Indiana farm with emphasis on harvest-time conditions.

Technically, the variables include crop timing, multiple-crop sequencing, rotations, own and custom harvest, fertilization, labor hiring and labor sale. The constraints included bi-weekly labor, land by period, machinery availability, a stochastic distribution of harvest time available and associated yields, crop rotation requirements. The producer-model objectives include income, risk and labor-leisure tradeoffs. The policy variables of interest include crop mix, stover harvest as it varies by harvest conditions, income, employment, and risk exposure. Data for the study were drawn from extension budgets, existing models, biomass-harvesting experiments and engineering calculations.

The models were used to examine alternative scenarios regarding harvest conditions, harvest equipment, stover price, product prices, hired labor prices. The model analysis was done as a follow up to a wider study (Tyner et al. 1979) directed toward the U.S. Congress and consideration of the appropriate agricultural synfuels component of energy policy.

#### Other Farm Level Environmental Studies

A wide variety of farm level studies have been done. For example, citing several that are directly related to environmental matters:

- \* Cashman, Martin, and McCarl examined pesticide bans.
- \* Apland, McCarl, and Miller studied the different irrigation equipment prices and risk attitudes as they influenced irrigation adoption while Ziari, McCarl and Stockle examined irrigation

system adoption and in stream flow.

\* Boggess, et al. examined the effects of different soil conservation incentives.

\* Bryant et al. examined the sensitivity of coastal farm performance to proposed USEPA erosion regulations.

## Regional Models

Probably the typical EPAT analysis would at least involve a regional focus. At such a level, one could use a set of "representative" farm models chosen to jointly reflect the component of regional production relevant to the study. The choice of representative farms will not be discussed here (interested readers should refer to the review in Onal and McCarl 1991).

The regional model contains the firm level representative farm models plus additional features for factor and possibly some product markets. For example, the land rental market may need reflect land rental rate determination across firms. There also may be regional limits for any hired labor, water, draft animals, and machinery shared among the firms. Yet another common regional model characteristic is a less than full specification of the firm submodels particularly in terms of the production possibilities. Discussion of why this is the case as well and how to avoid problems appears in the sector modeling section.

## Regional Case Study 1 -- Edwards Aquifer Water Allocation

The Edwards Aquifer (EA) in Central Texas is used by agricultural, municipal and industrial interests while feeding springs which support endangered species and recreation. Regional growth has resulted in increased EA reliance and has caused considerable fluctuation in springflow. Aquifer recharge varies widely with average pumping usage almost equal to average recharge and thus, little left for springflow. Management of the EA has become a hot policy issue resulting most recently in the declaration of the EA as a river. An ongoing modeling exercise has examined EA management issues (Dillon and McCarl 1991). A regional model was established which simultaneously depicts agricultural production, municipal water usage, industrial water usage and resultant springflow.

Technically, the model variables include pumping, crop production, allowable crop mixes, irrigation development, municipal usage, industrial usage, pumplift determination, aquifer lever determination and springflow determination. The constraints include labor, land, crop mix adherence, aquifer balance, water available by aquifer recharge state of nature, pumplift, springflow limits, and usage limits. The objective maximizes expected regional welfare across the recharge distribution and includes terms for net farm income, municipal water consumers' surplus, municipal water supply cost, industrial water consumers' surplus and industrial pumping cost. The policy variables of interest include regional welfare, springflow,

aquifer level, and pumping lift as well as the distribution across parties of income, water usage, and water prices. Data for the study were drawn from extension farm budgets, county cropping records, municipal and industrial water demand studies, agricultural engineering crop water requirement formulas, and an aquifer hydrology simulator.

Model use has involved examination of potential management and property right schemes, optimal water allocation, springflow limits, usage limits, farmer nonparticipation in a water market, population growth, and drought management.

## Regional Case Study 2 -- Jordanian Cropping Pattern Policy

The Jordanian government supports a cropping pattern policy designed to increase export revenues. This policy imposes mandatory acreage quotas. A study was done by Bessler and McCarl in conjunction with a Jordanian Government-USAID project and Sigma One Corporation. This study used a regional programming model of the Jordanian agricultural sector under the assumption that Jordan was a price taking country (a parallel study verified this assumption).

Technically, the model variables include regional crop mixes, water supply, tractors and hired labor acquisition as well as country wide exports, imports and domestic consumption. The constraints include regional labor, land, water, crop mix adherence, cropping pattern limits, and tractors as well as national commodity balances. The objective maximizes net agricultural income. The policy variables of interest include farm income, cropped area, employment, machinery use, cropping pattern, water use, trade balance and domestic food consumption.

Data for the study were drawn from extension farm budgets, regional cropping records, government policy documents, and regional trade statistics.

Model use involved examination of potential returns to a relaxation of the cropping pattern scheme including complete removal. Conclusions were drawn about the types of crops that would be grown under policy relaxation and the costs of the cropping pattern policy.

## Other Regional Studies

A number of other regional studies have been done. For example:

- \* Irrigation, machinery, dairy herd management, rural development and salinity control that were studied in the context of Mexican agriculture (Norton and Solis 1983).

- \* Agricultural policy in Northeast Brazil was examined (Kutcher and Scandizzo 1981).

- \* The agricultural benefits of salinity control in the Red River Basin in Texas are being examined by the author.

- \* Foreign trade conditions in Nicaragua were studied (Fajardo, McCarl and Thompson 1981).

\* Irrigation/Hydropower tradeoffs were studied in the Pacific Northwest (McCarl and Parandvash 1988).

\* Waste management and recycling were studied (Clayton and McCarl 1979).

\* Regional shrimp fishery management was considered in Onal et al. 1991)

## National - Sectoral Models

Considerable EPAT environmental action will probably involve policies or environmental forces which influence the entire country and agricultural sector. Sector models are relevant producer reaction models in such a case (I will not cover multi-sector or general-equilibrium modeling). Sector modeling differs from firm or regional modeling in terms of pricing and representative firm detail.

The pricing difference arises since sectoral forces usually render product and factor prices a function of the quantity produced and or consumed (i.e. demand and supply curves need to be considered). As a consequence, care is needed in specifying the appropriate model.

Consider first the recipe for an inappropriate model. Suppose one is modeling Egyptian long-stem cotton production. In doing such, suppose a linear rest of world demand curve is formed and a price times quantity term in the objective function. Thus, the model has a term maximizing Egyptian export revenue. Under such a case, a model generates the solution of where Egyptian producers act as perfectly discriminating monopolists in cotton exporting (McCarl and Spreen, 1980, or Takayama and Judge, 1971, review evidence pertinent to this statement). Such a solution is not consistent with observed behavior.

The common way of fixing such problems is to alter the objective function so one maximizes the area underneath the demand curve and above the supply curve which is called consumers' plus producers' surplus. Such a model simulates production in a perfectly competitive market (see the original development in Samuelson and the literature review in McCarl and Spreen 1980). Use of such an objective function complicates other matters, namely when risk exposure minimization is an important objective of producers and price risk is relevant then risk is an endogenous function and the appropriate way of preventing monopolistic risk avoidance behavior has not been fully worked out, nor has aggregation under risk (see the paper by Hazell and Scandizzo, 1974, or the paper by Lambert, McCarl, and Kaylen, 1992, for a discussion of these issues). Fortunately, in many circumstances, risk aversion has been found to be near zero when operating with aggregate level data.

The other major characteristic of sector models involves aggregation. Clearly in many sector studies, it is impossible to develop a full set of representative firm models for inclusion in the sectoral model. As a consequence, sectoral models usually deal with much more aggregate firm representations (i.e. one per state). This can introduce significant aggregation error if one

inadequately depicts response possibilities. An aggregation error example appears in the contrast of two studies involving with the potential of producing energy from U.S. agriculture corn byproducts. One study (Apland, McCarl and Baker 1981/82) used a firm level model and found when the value of corn byproducts was increased corn acreage declined. This reflected a crop-mix change induced by limited-harvest resources interacting with the increased harvest requirements for corn byproducts. However a sector-model analysis of the same problem (Tyner et al, 1979, and Bender and McCarl 1992) showed corn production increased with the corn-byproduct price. Clearly the aggregate representation exhibited aggregation error predicting a different kind of supply response. The firm model probably also overstated reaction since it used a fixed-price assumption and did not permit the firm to significantly restructure harvest capacity. Some answer between the two models may be the most appropriate. The lesson is that aggregate models should have a farm-level response component which adequately reflects response to the types of policies being investigated. This leads to two types of difficulties and their solutions.

Sector modelers and analysts must develop data reflecting an adequate set of production possibilities. Often one develops production possibilities based upon budgets generated by extension personnel or statistical surveys. Such budgets usually reflect a production pattern which existed at a point in time. As such they do not represent the available set of possibilities just the choice of the moment. Furthermore, the pattern given is conditioned by the particular set of factor and product prices in place at the time. If the corn price is high relative to the fertilizer price, fertilizer use will be high. On the other hand, if the corn price is low relative to the fertilizer, little fertilizer will be used. Either way, the full set of fertilizer alternatives will not appear if sampling. So how do you depict the relevant production possibilities? In such a case, one may well need to rely on expert, experimental or crop-simulator data (Dillon, Mjelde and McCarl 1989) to modify the budget data and generate production alternatives.

Second, one cannot usually afford to depict all different ways of producing a crop and all the constraints which influence choice on all farms. However, the producer response will take into account the technical forces, dietary preferences, resource restrictions and rotations which lead to a particular choice. In such a case, I recommend restricting the crop mix to fall within some combination of observed crop mixes (as argued in McCarl, 1982, and Onal and McCarl 1991). The observed crop mixes have restrictions implicitly coded into them on the firms' employment of resources and rotations. The historical mixes may need to be augmented for an environmental analysis if the actions are anticipated to cause production outside the historically observed crop mixes. If this is the case, then either use expert opinion or auxiliary farm level models (as done in Hamilton, McCarl, and Adams 1985) to make a richer productions possibilities set.

#### Sectoral Case Study 1 -- Egyptian Water Control

A study was done regarding water control and cropping patterns in Egypt. By the mid 1980's, the strategic reserve of water in the High Aswan Dam had fallen from a two-year to a two-month supply.



But, Egyptian water-use patterns did not adjust substantially. As a consequence a study was undertaken to examine High Aswan Dam release and cropping-pattern policy in the face of future prospects for water availability. This was done using an Egyptian agricultural sector model (McCarl and Attia 1988) in conjunction with a High Aswan Dam-simulation model.

Technically, the sector model variables include a five-region breakdown of crop production, crop processing, livestock feeding, domestic consumption, exports, imports, transport, hired labor, subsidies and taxes. The constraints include regional labor, land, vegetable limits, cropping pattern limits and livestock nutritional characteristics as well as national commodity balances and water availability. The objective maximizes net agricultural consumers' and producers' surplus after imposition of government taxes and subsidies. The policy variables of interest include consumers welfare, price levels, farm income, cropped area, employment, government subsidy costs, government tax revenues, water usage, imports, exports, trade balance and domestic food consumption. Data for the study were drawn from agricultural ministry budgets, regional cropping records, government statistical documents, consumer demand studies and world trade regional trade studies.

The sectoral model was utilized to value the effects of alternative water release levels coupled with alternative cropping patterns. Cropping pattern commitments were assumed to start before full information on the available water was known. The High Aswan dam simulator was utilized to predict carry over water in the dam as well as the value of the hydroelectric output under various release policies and water years. The sector model was used to predict the agricultural benefits of various water releases under alternative cropping patterns. In turn, a decision theory framework was utilized to examine economic returns and their variability as well as retained water across cropping pattern and dam release policies.

## Sectoral Case Study 2 -- Ozone Control

A common use of sectoral models by the author has involved the environmental assessment of changes in air quality. One study involved the agricultural benefits of alternative U.S. ozone standards. There a U.S. agricultural sector model was employed to study the effects of changes in ozone concentrations (Adams, Hamilton and McCarl 1986).

Technically, the model variables included activities for a 63-region breakdown of crop production, crop-mix choice, irrigation, livestock production, labor supply, land supply, water supply, processing, livestock feeding, domestic consumption, exports, imports, fixed price input acquisition and farm program subsidies. The constraints include regional labor, land, water, crop mixes, policy restrictions, and livestock feed needs as well as national commodity balances. The objective maximizes net agricultural consumers' and producers' surplus after imposition of government subsidies. The policy variables of interest include consumers welfare, price levels, farm income, cropped area, employment, government subsidy costs, water usage, imports, exports, trade balance and domestic food consumption. Data for the study were drawn from USDA cost of production

surveys, extension farm budgets, regional cropping records, government statistical documents, consumer demand studies, experimental studies of ozone concentration effects on crop yields and world trade studies.

The model was utilized in conjunction with the crop yield and water use results of ozone chamber experiments to forecast the agricultural sector consequences of ozone concentration variations (Adams, Hamilton and McCarl 1986). The study was incorporated as part of a report to Congress and the agricultural benefits were used to partially justify changes in clean air regulations. Similar analyses were also done on the effects of acid rain (Adams, Callaway and McCarl 1986), carbon sequestration (Adams et al. 1991) and global climatic change (Adams et al. 1989, 1990).

### Other Sectoral Studies

A number of other sectoral studies have been done. For example:

- \* There were a number of studies done involving policies aimed toward irrigation projects, and other development issues in the context of Mexican agriculture (Norton and Solis 1983)

- \* Studies have been done regarding U.S. erosion policy (Heady and Srivistava 1975) as well as Alt et al., pesticide bans (Burton and Martin 1987), fertilizer use changes (Meister, Chen and Heady 1978) and biofuels production (Tyner et al 1979).

- \* Studies have been done on Indus Basin water management (O'Mara and Duloy 1984).

### An Aside -- Doing a Programming Study

In passing, it is worthwhile recommending the usage of GAMS software (Brooke Kendrick and Meeraus 1988) for doing studies in this arena. This software permits solution of large models on micro computers, facilitates documentation and later use of models, and allows use by varied personnel. I feel these attributes would be highly desirable in the EPAT environment. I believe the sister APAP project runs training sessions in GAMS.

### CONCLUSIONS

This paper has only scratched the surface of the very large mathematical programming, environmental analysis area. Analyses in this area generally involve the quest for optimal policy. This question may be approached formally through multi-level programming or informally through scenario analysis. At this point, operational issues largely dictate scenario analysis, but research is ongoing on formal optimal policy discovery. In either context, mathematical programming provides a useful

framework to resolve questions about how producers would respond to environmental incentive and regulatory programs. Models permit investigation of possible policies so as to both steer producer responses and avoid unanticipated responses. Fundamentally, it is important to recognize policy objectives or items of concern, then build producer- response models which forecast how those objectives would be affected if policies were implemented.

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INTRODUCTION

Apparently there has been interest in the nature of the case example findings within my manuscript "Mathematical Programming for the Resource Policy Appraisal Under Multiple Objectives" published by the Environmental and Natural Resources Policy and Training Project as Working Paper No. 6 in November, 1992. This addendum provides additional information on findings within each case study. Beyond that I would urge readers interested in more detail to consult the references.

Farm Level Case Example 1 - Indonesian Technology Prospects (page 10)

Several findings were generated. First, it was found that the prospects for food production, particularly rice, were bright as the technologies examined were found to have considerable potential to expand production in an economically efficient manner. In fact, the study was done at a time when Indonesia was just on the border of being food deficient (late 1970's), but over the few years after the study the country moved forward food self sufficiency with expansions in food exports partially due to technological change, thus the results of the study were borne out. Second, conclusions were made within the study about the need, particularly in the upland areas, for credit and other types of incentive schemes, directed toward farming systems rather than crop specific programs. Third, a technology that allowed one to get two rice crops out of wet season water was investigated. Within the study, the results of this technology were compared to year-round water management, it was found that the presence of the cropping technology reduced the returns to year-round water control irrigation infrastructure by over 80 percent. In turn, this finding led to policy debates within the sponsoring organization as to the appropriate levels of investment and eventually a reappraisal of a large lending program. Finally, the results were used in support of arguments for additional research funding in the context of a sector lending program.

Farm Level Case Study 2 - Corn Byproducts for Biofuels (page 11)

The results of this study showed that:

1. crop residue is an expensive source of energy;
2. producers would produce a highly variable amount of crop residue depending on harvest time weather conditions;



3. crop residue harvest competed dramatically with harvesting of other crops and caused a crop mix alteration; namely corn acreage was reduced with wheat and soybean acreage increased, allowing fall harvest time to be freed up;
4. larger harvesting equipment and new technology would help the situation;
5. in the short-run, the supply curve of residue would be highly inelastic, and;
6. the long-run supply curve was very responsive at low prices with the quantity supplied between \$30 and \$40 a ton of residue varying by a factor of 2.

#### Regional Case Study 1 - Edwards Water Allocation (page 13)

The results of this study indicated that emerging changes in water consumption patterns in the region would lead to a disparity of water use values between nonagricultural and agricultural users. This indicates that it would be most useful if ground water rights and an associated market for such rights were put in place to allow transfer of water from the low to the high value users. Second, agriculture was found to be a very vulnerable sector from an overall economic optimum perspective as demand grows, since agriculture is a much lower valued user. Third, protection of springflows was found to influence returns, costing as much as \$40 per acre foot of water. Fourth, schemes which limited the sectoral amount of water without allowing transfer between the sectors were found to be efficient at first but to have higher welfare costs as time went on. Finally, it was found beneficial that agriculture use water in periods of high flow and not suspend water use in periods of low flow thereby allowing water use by the highest valued users in the critical periods but permitting beneficial agricultural production in the water surplus periods.

#### Regional Case Study 2 - Jordanian Cropping Pattern Policy (page 13)

The basic conclusion of this study was that the cropping pattern policy which limited the quantity of high-valued vegetable export crops was economically costly. It appears that by suspending the policy and allowing larger quantities of certain exports to be produced, the prices received would not change and producer welfare would increase.

#### Sectoral Case Study 1 - Egyptian Water Control (page 17)

The basic results of this study were two. First, by employing a conservative water release strategy and cutting back on the heavy water using rice and sugar crops, that a substantial opportunity for increasing the water supply available from in the High Aswan

Dam and the efficiency of water use existed even in the face of potentially serious drought effects. Second, this study was completed before one of the larger floods in recent history and this was found to be unfortunate. The subsequent floods and level of inflows in the last several years made the drought oriented study of little interest to policy makers. In a related study, the same model was also used to look at incentive and pricing policies and its effects on land allocation and the value of water. It was found that pricing policies were a very big factor in farm returns and production choice. Lowering in price differentials between farm production and exports caused by government policy would cause greater production of certain farm commodities, increase social welfare and, in fact, increase government tax revenues.

#### Sectoral Case Study 2 - Ozone Control (page 17)

The results of this study showed that agriculture was very vulnerable to ozone with roughly a \$200 million change in the net welfare of the agricultural economy. Comparison of this outcome with the cost of cleaning up ozone, made agriculture almost large enough in benefits to justify the anticipated provisions on its own. The acid rain analysis showed that acid rain benefits agriculture. The carbon sequestration analysis showed substantial implications for agriculture from increases in tree planting to prevent global climate change and that expanded tree planting would lead to a reduction in welfare and activity in the forest sector, the global climate change effects have, in the most recent work done by the author, been shown to be positive for the U.S. agricultural economy.

In all of these case studies, the basic findings were used to generate a mixture of qualitative and quantitative insights regarding the potential performance of the modeled entity. Implications were drawn for overall economic performance as well as income distribution, and when possible environmental attributes.